I. C. 7128 JULY 1940

UNITED STATES
DEPARTMENT OF THE INTERIOR
HAROLD L. ICKES, SECRETARY

BUREAU OF MINES
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INFORMATION CIRCULAR

CONSTRUCTION OF THE BINGHAM-COPPERFIELD VEHICULAR TUNNEL

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

CONSTRUCTION OF THE BINGHAM-COPPERFIELD VEHICULAR TUNNEL[1]

By L. S. Breckon[2]

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2/ One of the consulting engineers, Bureau of Mines, and chief geologist, Utah Copper Co., Bingham Canyon, Utah.

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INTRODUCTION

This paper describes the methods and equipment used by the Utah Copper Co. in constructing a vehicular tunnel at Bingham Canyon, Utah. Completion and use of this tunnel for vehicular and pedestrian traffic permitted abandonment of the long-used county highway connecting Bingham and Copperfield. Expanding operations of the Utah Copper open-cut mine necessitated construction of a vehicular route away from the ore body. The site of the tunnel is well beyond ultimate pit slopes and future mining operations. The tunnel not only diverts vehicular and pedestrian traffic but also carries creek water, copper water, sewage, pipe lines, and power and telephone cables between the two communities.

The dimensions of the tunnel permit one-way traffic only. Traffic-control lights have been installed. Owing to the possibility of accumulation of carbon monoxide gas from automobile exhausts, automatic gas detectors has been installed at various stations. These detectors control the operation of a large exhaust fan situated at the upper portal of the tunnel.

A key plan and profile are shown in figure 1. Details of the general design in cross section are shown in figure 2. Owing to a 450-foot difference in elevation between the two portals, the tunnel was driven on a grade of 6.43 percent. This grade necessitated the use of special equipment for removing material broken in driving. The tunnel, which is owned by Salt Lake County, Utah, is concreted throughout for safety and to keep down maintenance costs. It was built by the Utah Construction Co.

The 6,975-foot tunnel has a full-arched back with straight walls. Inside the concrete lining it is 16 feet 4 inches wide to a height of 10 feet above the finished roadway surface, topped by an arch sprung to a radius of 8 feet 2 inches. On one side is a sidewalk, built over the sewage and drainage flume, which occupies about one-quarter of the tunnel's width. (See fig. 2.) The tunnel is lined throughout with reinforced concrete to reduce the hazard of falling rock as well as maintenance cost. Excavation was completed before the lining was begun. As the tunnel was designed for one-way traffic only, emergency turn-outs were necessary; they were excavated at several points and were gunited.

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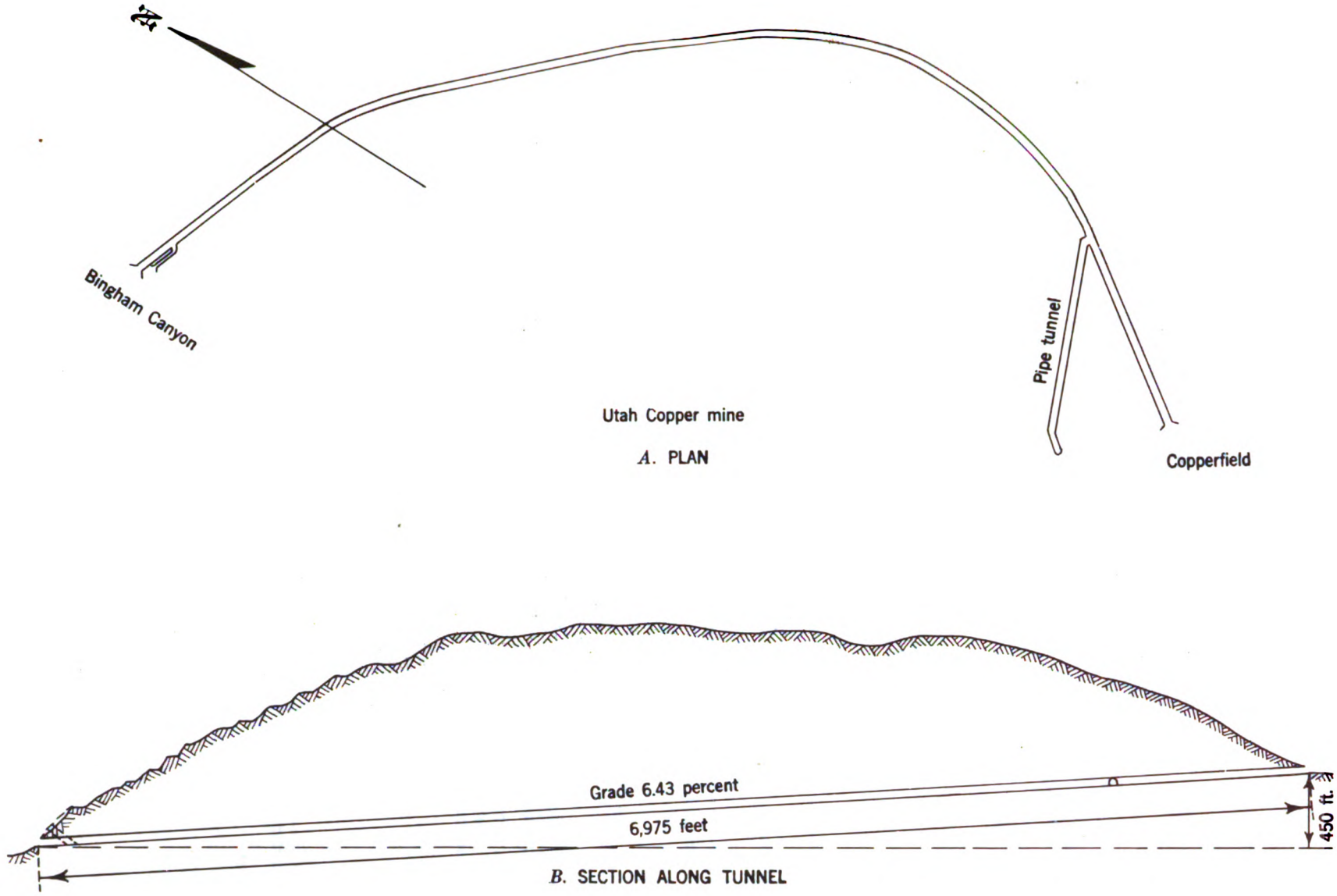

Figure 1.—Plan and section of Bingham–Copperfield vehicular tunnel.

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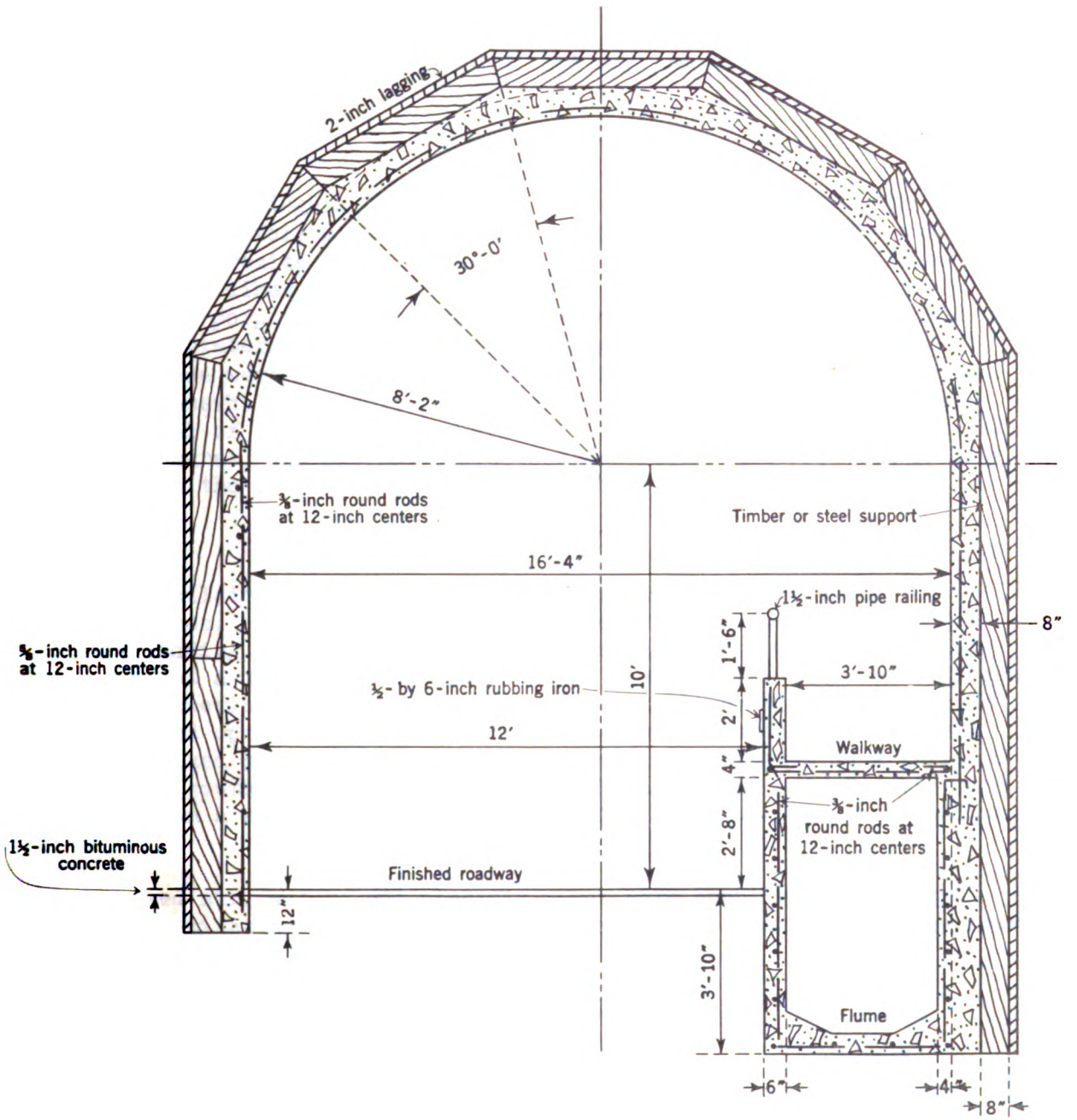

Figure 2.—Typical section through Bingham–Copperfield vehicular tunnel.

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Traffic is controlled by means of red and green lights at both portals, operated by photoelectric cells and electric relays. The ventilating system consists of gas detectors at several stations that automatically control the large exhaust fan and air door at the upper portal.

The tunnel was begun April 7, 1937, and was completed on January 1, 1939, at a cost of $1,400,000.[3]

GEOLOGY

Geology of the Bingham district has been described in detail by J. M. Boutwell[4] and therefore will not be discussed in this paper. The tunnel was driven through quartzite and calcareous quartzite in which are intruded several sills and dikes of monzonite porphyry. Owing to the close proximity of the monzonite porphyry stock, the quartzite was shattered and crushed and required close timbering support. All bedding planes dip to the north at about 35°. These were cut at approximately right angles by the tunnel and made driving somewhat difficult as the bedding faults were reached. Water was found in several of these faults as well as in some of the near-by vertical faults and fissures, and extensive grouting was required to prevent passage thereof through the concrete lining of the tunnel.

PREPARATION OF SITE

Several buildings near the portals were removed to make space for the tunnel approaches. Soil, fill, and detrital debris were removed by a 3/4-yard shovel loading into 5-cubic-yard dump trucks. These were dumped into railroad cars at a considerable distance from the portals. Lack of dump space necessitated removing all excavated material from the canyon. Broken rock from underground operations at the north portal was hoisted from a nearby bin on an inclined skipway and dumped into waste cars spotted on a railroad track. At the south portal the waste material was loaded into 5-cubic-yard dump trucks from a storage bin and hauled half a mile to a railroad loading spur.

Compressed air, water, and electric power were supplied by the Utah Copper Co., eliminating expensive installations by the contractor. The crew and staff were housed in the two communities.

EXCAVATION OF TUNNELS

General

The tunnel was driven from the two portals, full-face headings being used except in heavy ground, where a top heading was driven for a short distance in advance of the main face. A drill jumbo mounted on the frame of a 5-ton truck was used and a full face was drilled in a clean breast, which speeded the operations.

3/ Engineering-News Record, Editorial comment: Feb. 16, 1939.

4/ Boutwell, J. M., Economic Geology of the Bingham Mining District, Utah: Geol. Survey Prof. Paper 38, 1905, pp. 279-280.

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Three shifts of 8 hours each were worked; the shifts changed at the face. Heading crews were men skilled in this type of underground work. The cycle of operations - drilling, blasting, mucking, and timbering - was supervised by a shift boss solely responsible for all work on his shift.

Drill Carriages

The drill carriages (fig. 3) used in driving the tunnel were built by the contractor on obsolete trucks that could be moved to the face under their own power or be sidetracked when other equipment was used. When raised horizontally, the staging on the sides of the carriage extended the full width of the tunnel, thus permitting drills to be set up at the perimeter of the face. The staging was supported entirely by the carriage and could be raised or lowered quickly.

During timbering operations carriages were used as platforms to support timber, blocking, wedges, and hand tools. During drilling they were used as platforms to hold extra machines, drill steel, hose, spare bars, oil, hand tools, and various other equipment.

A system of air and water lines acted as struts, supports, and braces on the carriage. From the manifolds of these lines, 3/4-inch air hose and 1/2-inch water hose were connected to the drilling machines. The supply lines on the carriage were attached to the air and water supply lines in the tunnel by a 50-foot length of 6-inch rubber hose. About 10 minutes was required to block the carriage and connect the hoses preparatory to drilling, after the carriage was placed at the face.

Drilling

Six machines with automatic feed were mounted on the carriage; these were arranged so that two machines would drill the top holes; two the side holes, and two the lifters and sewer holes.

Several types of drill rounds were used during the early stages of the operations. The V-cut, 43-hole round finally adopted is shown in figure 4. Holes ranged in depth from 4 feet 6 inches to 5 feet, with 6 feet for the cut holes. The drilling time averaged about 2 hours and 5 minutes a round.

Blasting

With completion of drilling, the upper holes were charged from the carriages, which were then removed, and the lower holes were loaded and the round wired for electric blasting. The explosive was 40-percent Gelamite in 1-1/2- by 8-inch cartridges. No stemming was used. No. 8 electric delay detonators of 0 to 9 delay were employed; the primer was placed above the center of each charge. The detonators were connected in parallel and shot from a 440-volt firing line, which was disconnected except when ready to blast. The shift boss was responsible for firing the round and reshooting misfires. This method of loading and detonation proved satisfactory;

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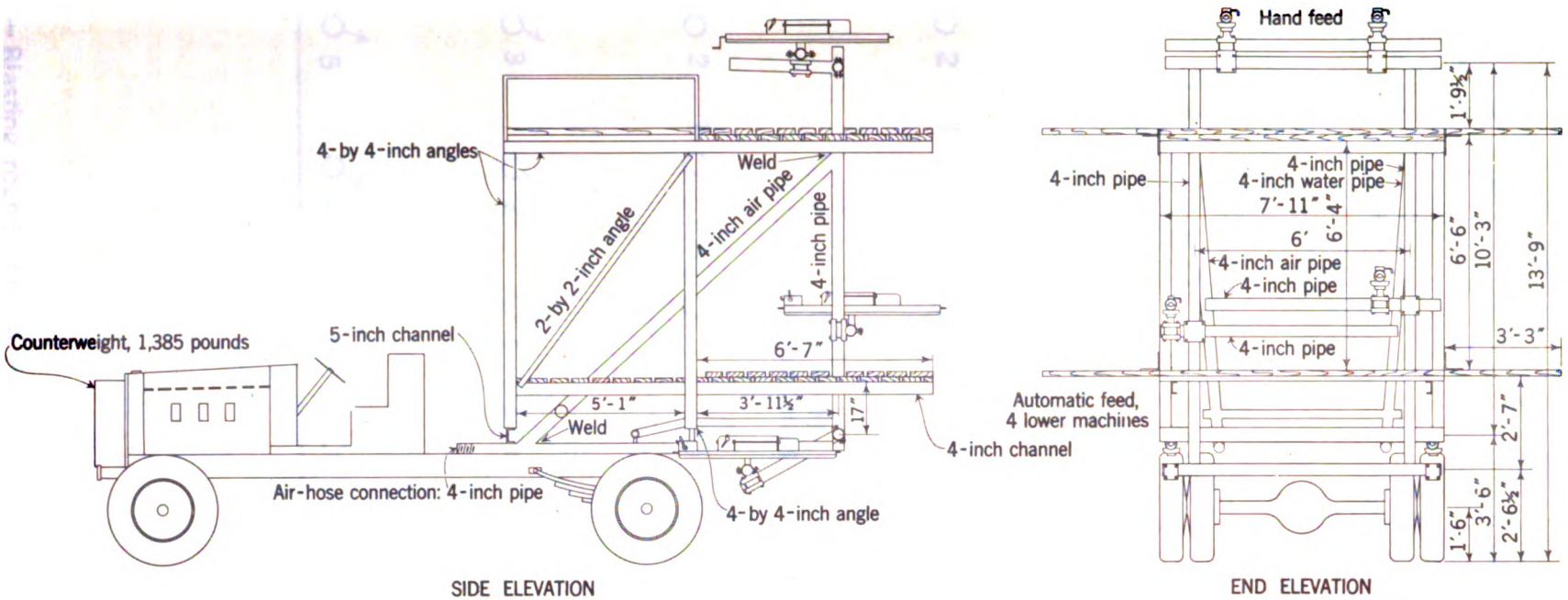

Figure 3.–Jumbo drill carriage used in Bingham–Copperfield vehicular tunnel.

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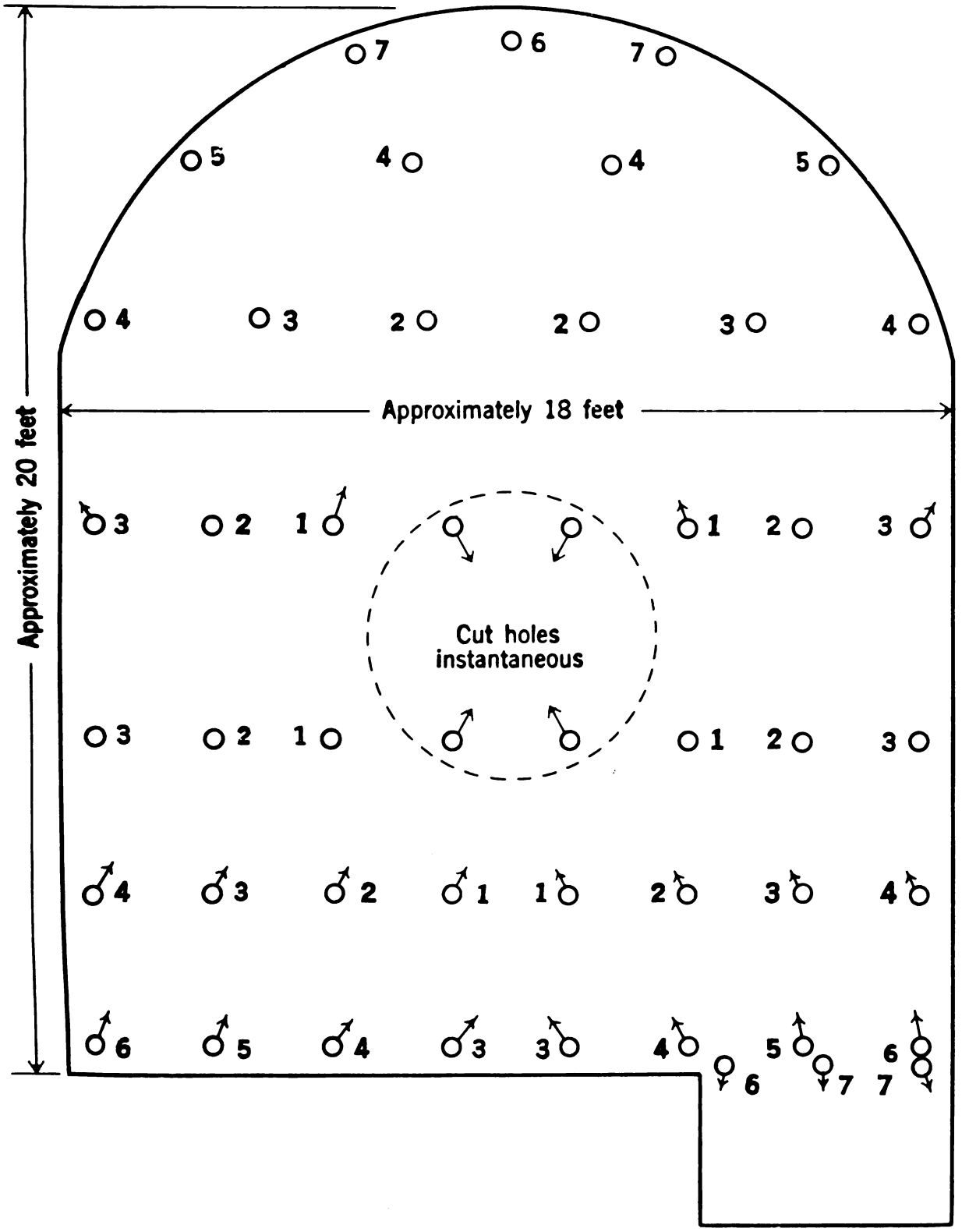

Figure 4.— Blasting round used in Bingham-Copperfield vehicular tunnel.

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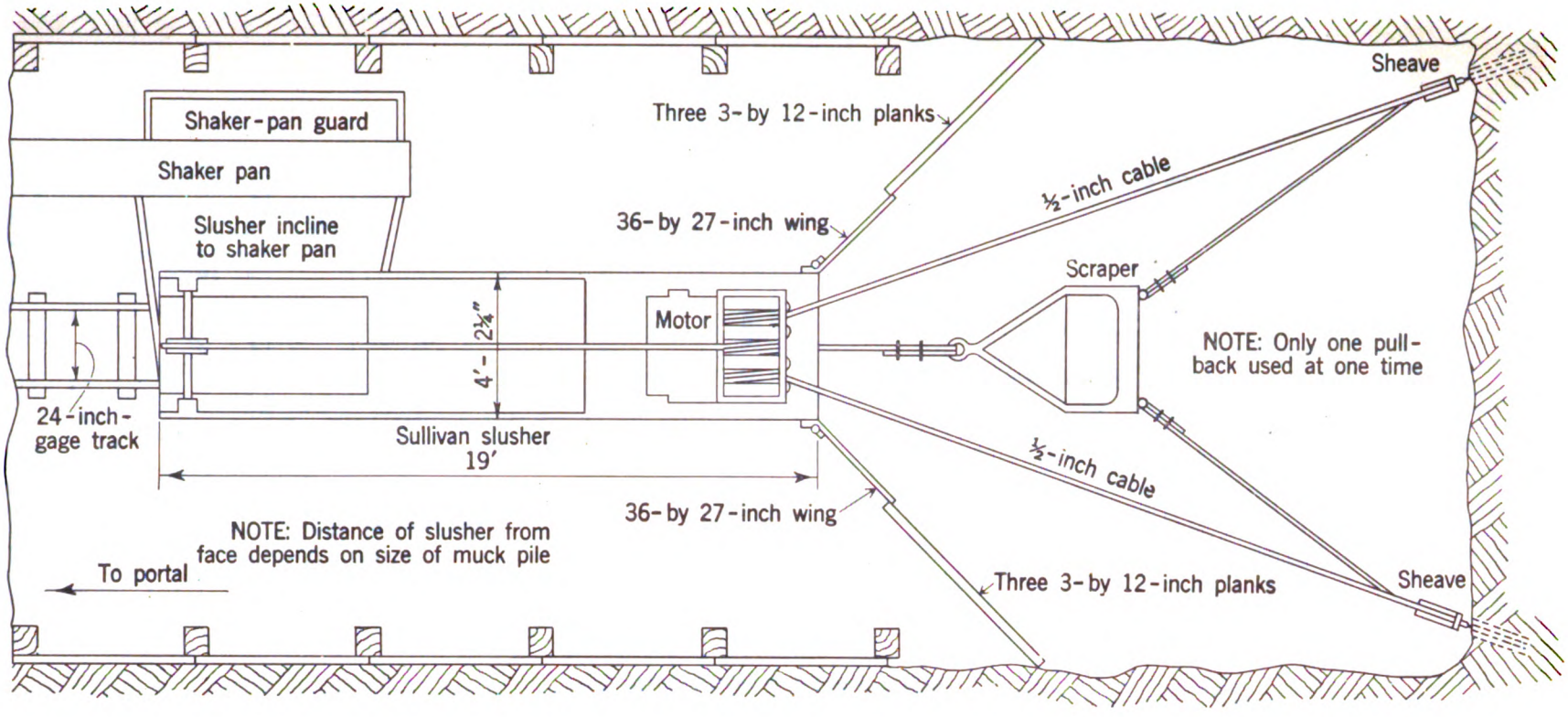

Figure 5.—Plan of Sullivan slusher in tunnel.

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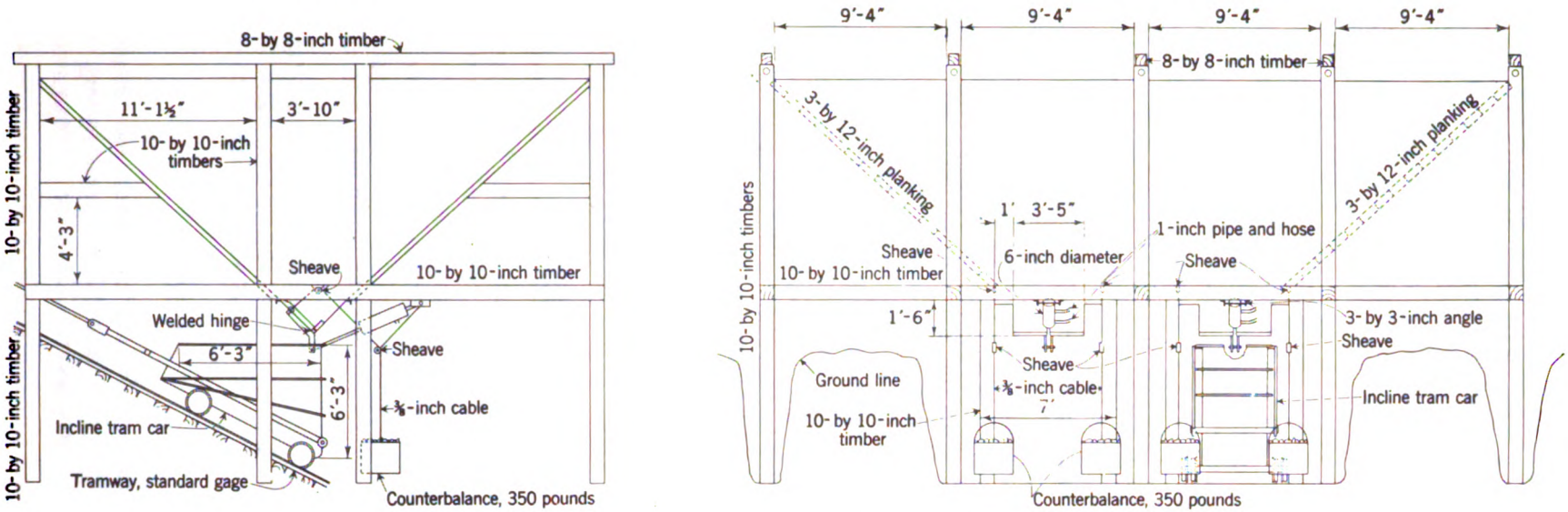

Figure 6.—Spoil bin at north portal of tunnel.

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there were few misfires, delayed or burned-out holes, or out-of-sequence firing. Loading and shooting of the holes required about 20 minutes, with 30 minutes' delay allowed for the removal of fumes.

The break per round averaged about 5 feet. The rock broke into small fragments, making 12.3 to 13.3 cubic yards of spoil for each foot advanced.

Loading

Loading was begun immediately after a heading was clear of powder fumes. The first excavator used in the north heading was a power shovel mounted on caterpillar tractors; it loaded into 5-ton dump trucks. After several hundred feet was driven, a slusher and conveyor-belt system was installed. This consisted of a slusher at the face (fig. 5) filling a shaking pan-type loader, which in turn discharged onto a belt carrying the broken material to the portal. This equipment was used until a wet, sticky material was encountered, which greatly reduced the efficiency of the belt. A 24-inch-gage track was then placed along one side of the tunnel and a hoist haulage system was installed. Bottom-dump cars of 4-cubic-yard capacity were drawn up to the slusher by a tugger hoist. The cars transported the broken material to a 100-ton flat-topped storage bin (fig. 6) located at the portal of the tunnel. From this point the excavated material was loaded into skips of 4-cubic-yard capacity, hoisted up a 38° incline a distance of 378 feet, and delivered to Utah Copper waste-disposal cars. A single-drum 100-horsepower hoist with a hoisting speed of 150 feet per minute was used in elevating this material. The average time of the hoisting cycle was about 4 minutes.

The broken material from the south heading was loaded into cars of 4-cubic-yard capacity; a car hoist above the waste storage bin at the portal of the tunnel hauled the cars against the adverse tunnel grade.

Loading out a 5-foot round required an average of about 3-1/2 hours.

Timbering

Temporary timbering used in the tunnel varied in dimension according to the character of the ground. Normally, 8- by 8-inch sets with five-piece segment caps spaced on 5- to 6-foot centers (fig. 2) were used. In heavy ground 10- by 10-inch or 12- by 12-inch timbers were used, with a spacing down to 3-foot centers. Lagging sizes varied according to the nature of the ground, with 2 by 12 inches as the standard dimension.

Timber was handled from the drill-carriage platforms, which facilitated the placing of segment caps, wedging, and lagging. An average of 1 hour and 25 minutes was required to stand a set.

Ventilation

A ventilation system was necessary to clear fumes from the tunnel during blasting and trucking operations. A 15-inch Sturtevant 5,000-cubic-foot positive-type blower connected to a 100-horsepower motor was used. The blower

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removed the fumes through a 24-inch 16-gage ventilation pipe supported in the upper part of the tunnel and carried to within 400 feet of the face. A 24-inch vent tube was used between the end of the ventilating pipe and the face of the heading. This installation proved satisfactory and removed powder gases within 20 minutes after blasting.

Time Cycle

A complete cycle was made each shift, as follows:

	Hours	Minutes
Setting up.....		10
Drilling.....	2	05
Loading holes....		20
Ventilation.....		30
Loading.....	3	30
Timbering.....	1	25
Total.....	8	

Labor

A shift at the heading comprised 12 miners, a nipper, and a shift boss. This crew was trained to all the phases of underground work. A general foreman was responsible for the three shifts.

In addition to the men actually engaged in driving the tunnel, a large force was required on outside work for trucking, timber framing, sharpening steel, and general maintenance. Ninety-nine workmen were employed at each heading and in addition 20 men were employed in shops, where work was done for both headings, making a grand total of 218 men.

The following tabulation shows the distribution of labor and supervision for three 8-hour shifts, which were worked daily:

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Underground at each heading:		
Foreman	1	
Shift bosses	3	
Nippers	3	
Miners	36	43
At surface at each heading:		
Master mechanic	1	
Dumpmen	6	
Roustabouts	8	
Carpenters	6	
Electricians	3	
Electricians' helpers	2	
Hoistmen	3	
Shovelmen	6	
Oilers	6	
Truck drivers	12	
Time keepers	3	56
Total one heading		99
Total both headings per 24 hours		198
General shops:		
Blacksmiths	2	
Blacksmiths' helpers	2	
Drill repairman	1	
Garage mechanic	1	
Mechanics	4	
Mechanics' helpers	3	
Welder	1	
Laborers	4	
Warehousemen	2	20
Grand total		218

Shop Equipment

The general service shop for the tunnel operations contained the following equipment:

1 I.R.No. 5 drill-bit sharpener
1 oil furnace
1 emery wheel
1 300-ampere electric welding machine
1 100-ampere electric welding machine

Tunnel Progress

Operations were simultaneous at the north and south portals. Progress at the north heading was more rapid than at the south, where, at 278 feet, a large shear zone was encountered.

The average progress for both headings was 12.62 feet per 24 hours. The best day's excavation was 35 feet; the best month's advance was 602 feet.

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Tabulated progress data for both portals follow:

South portal:

Heading begun.....April 23, 1937
Heading completed.....February 19, 1938
Total footage.....3,014

1937	Footage	Remarks
April	21	
May	344	
June	408	Heavy swelling ground, doubling sets.
July	34	Started concrete, heavy ground (80 feet completed).
August	58	Concreting - 118 feet during month.
September	135	Concreting - 80 feet during month.
October	195	
November	566	
December	324	
1938		
January	450	Five days delay.
February	479	Completed Feb. 19, 1938.
	3,014	Feet
		Best month.....566
		Best 24 hours..... 21
		Average per day.... 10.58

North portal:

Heading begun.....April 7, 1937
Heading completed.....February 1, 1938
Total footage.....3,961

1937	Footage	Remarks
April	35	
May	226	Shaker would not work May 30, 1937.
June	423	Started using shovel June 1, 1937.
		Started using cars June 15, 1937.
		Started using steel sets June 26, 1937.
July	161	Started driving Pioneer heading, July 1, 1937 (heavy ground).
August	602	
September	503	
October	480	Worked 28 days.
November	556	
December	490	Worked 28 days.
1938		
January	450	
February	35	Completed February 1, 1938.
	3,961	Feet
		Best month.....602
		Best 24 hours..... 35
		Average per day.... 14.67

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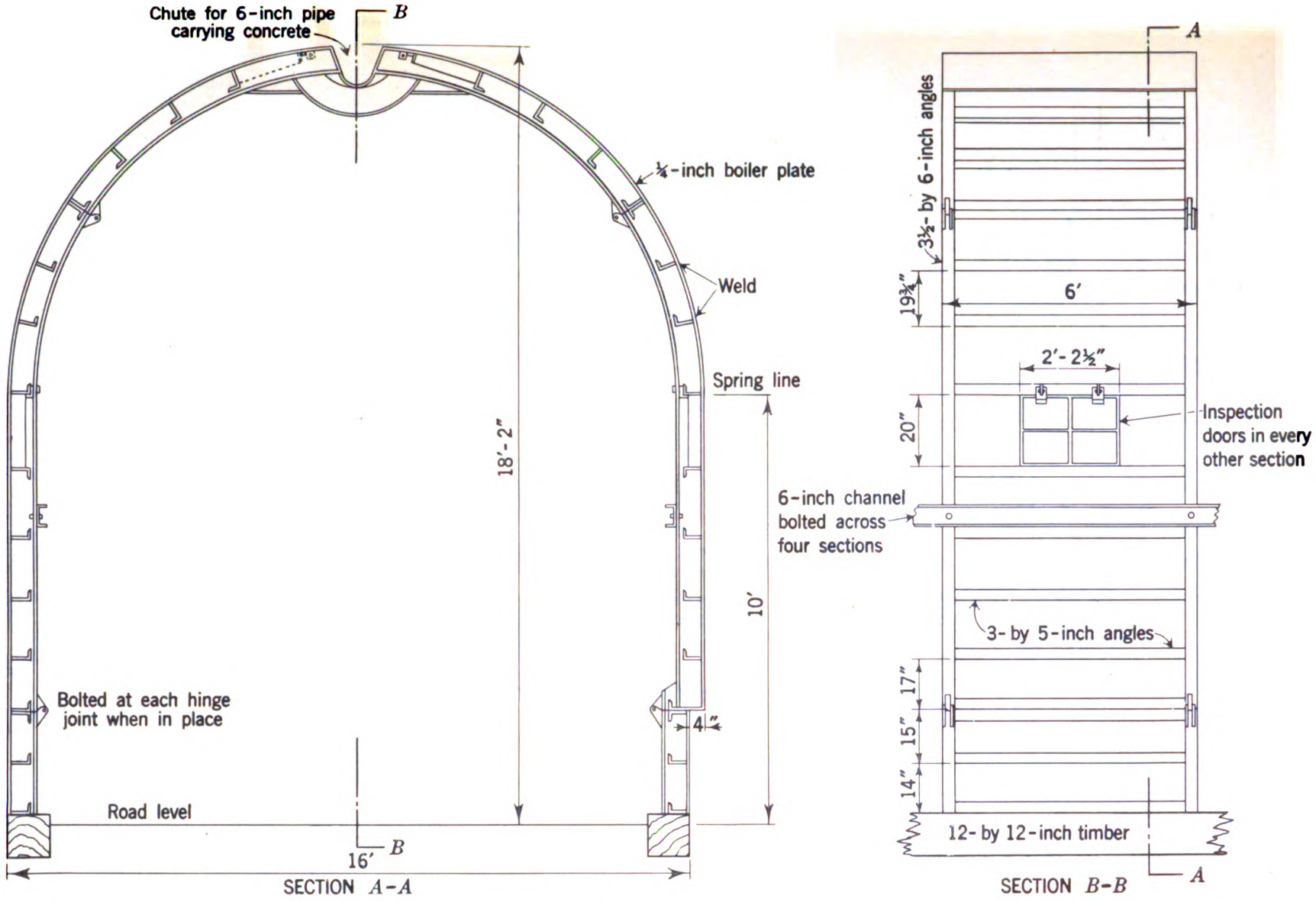

Figure 7.—Concrete forms used in Bingham-Copperfield tunnel.

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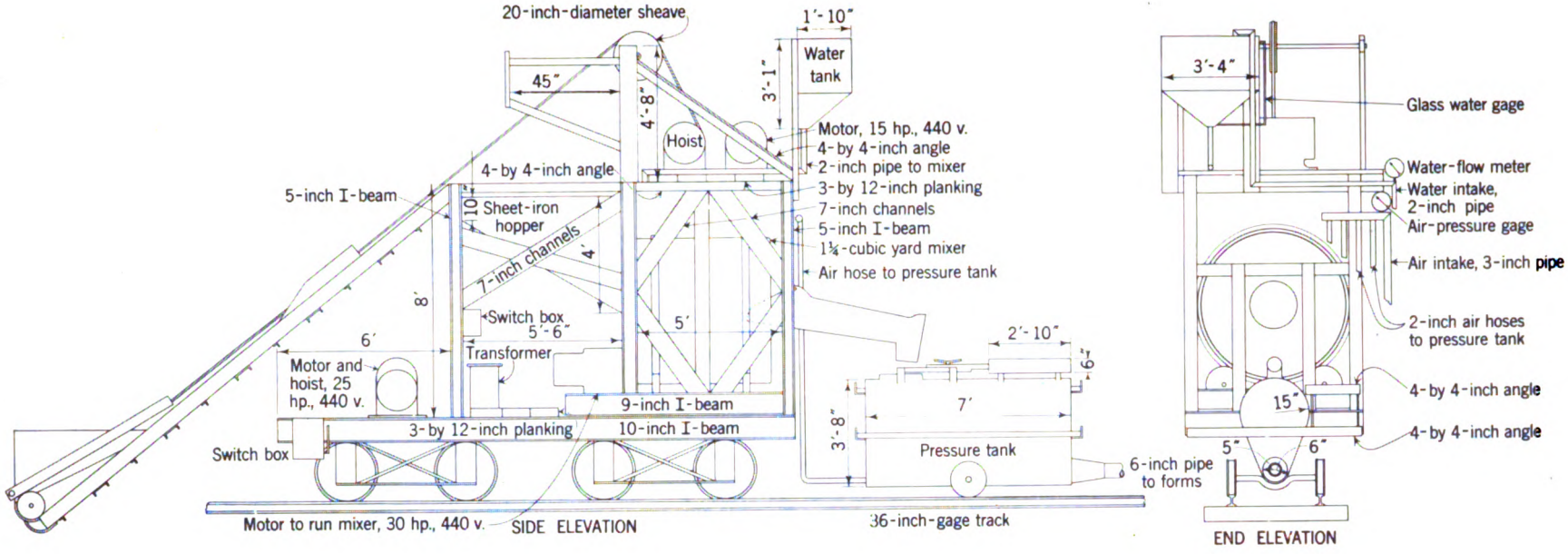

Figure 8.—Concrete mixer used in tunnel.

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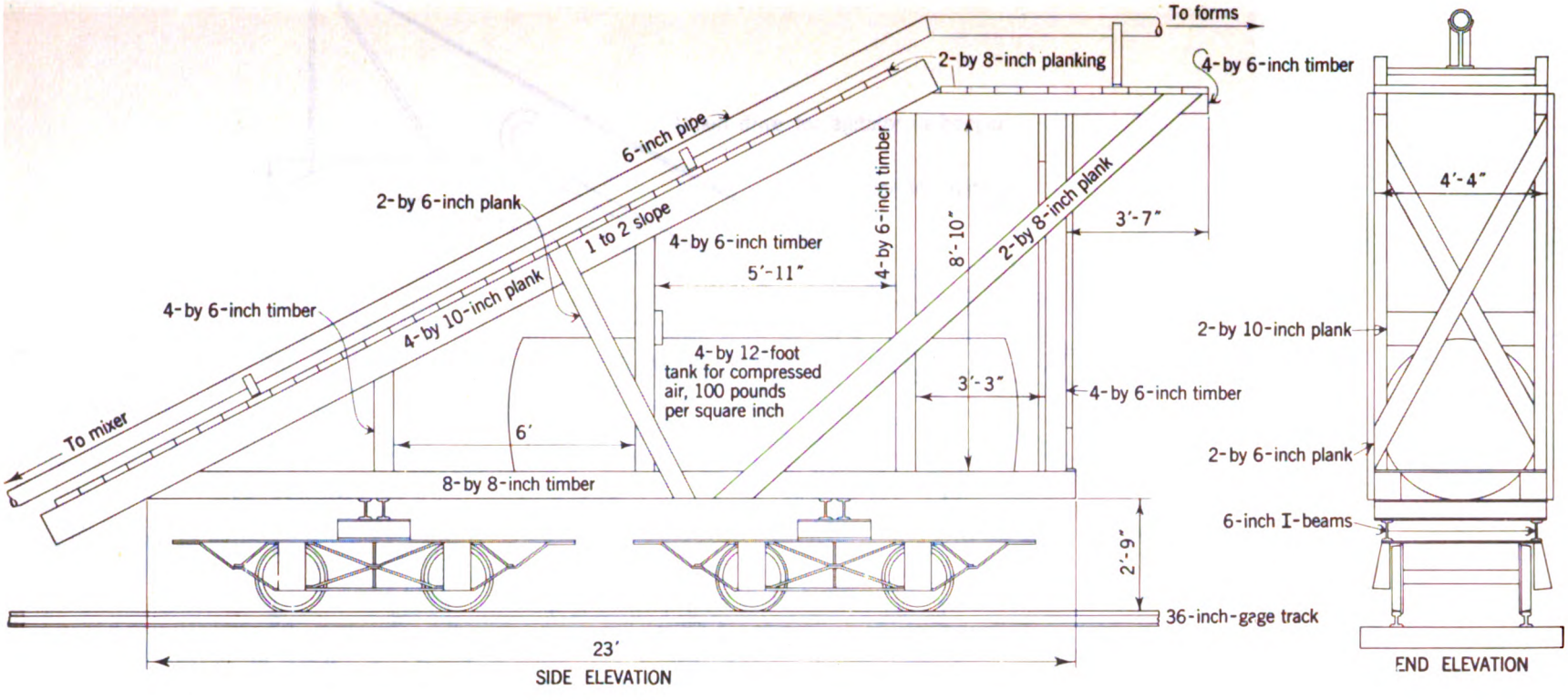

Figure 9.—Ramp carrying pipe to forms in tunnel.

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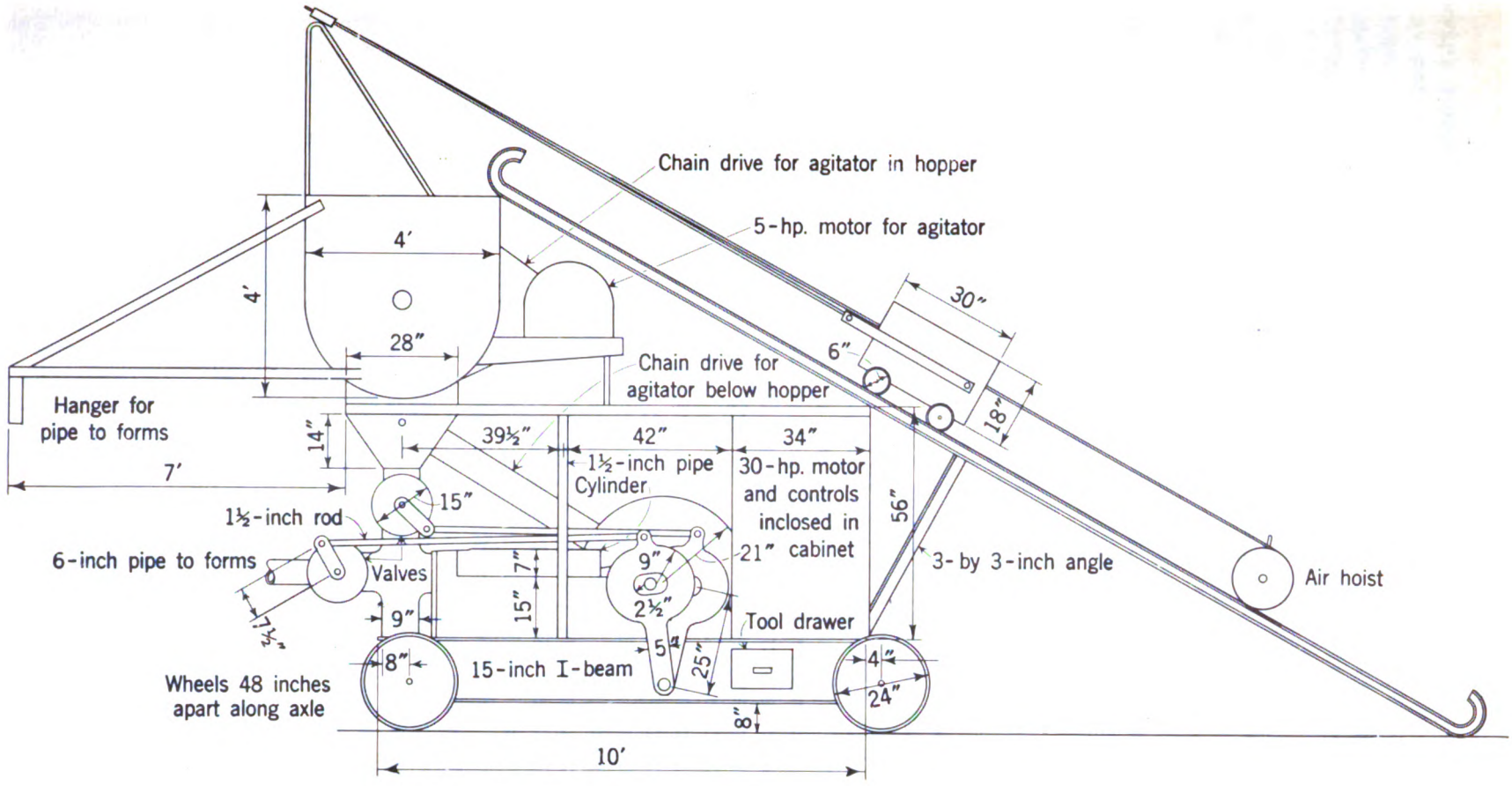

Figure 10.—Rex Pumpcrete used in tunnel.

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CONCRETE LINING

The entire tunnel was lined with concrete. The excavation was completed before lining operations were begun, except 278 feet, near the south portal. Here, the large shear zone required special procedure, as the ground was extremely heavy. The temporary supports being used were replaced by 12- by 12-inch timbers, stood as a solid wall, but even with this support immediate concreting of this particular section without removing the timbers proved necessary. The concrete was mixed in the ratio 1 : 2-1/2 : 4 by a portable electric mixer having a capacity of 7 cubic feet per batch. Concrete was poured from wheelbarrows to the side forms and shoveled by hand from the wheelbarrows into the top forms, where it was tamped into place. The normal pouring speed was 4 cubic yards per hour. The forms for the sides were built in 6-foot-square sections made up of 2- by 6-inch lumber nailed to 2- by 12-inch pieces. The arch-top forms were made by cutting the 2- by 12-inch pieces to the desired radius and laying the 2- by 6-inch pieces on top.

The main concreting operation, as carried on through the major part of the tunnel, was more systematic. Steel forms were made up in 6-foot sections, as shown in figure 7. These sections were bolted together in 72-foot sections. Wooden shore blocks were used at the sill and spring line. Reinforcing steel consisted of 7/8-inch round rods on 12-inch centers in the solid ground and 1-inch-square rods on 6-inch centers in heavy ground; the horizontal pieces were 3/8-inch round on 12-inch centers. A concrete mixture of 1 part cement, 2 parts sand, and 4 parts gravel with a maximum size of 1-1/2 inches was specified. The ingredients were weighed outside the portals in proportions of 575 to 600 pounds of cement to 3,150 pounds of premixed aggregate per batch. Each batch was hauled into the tunnel dry in separate compartments of 2-ton dump trucks, two batches to the truck. The mixture was transferred to a specially built electrically driven mixer in the tunnel, which produced a concrete of about 125 pounds per cubic foot in weight. The mixer (see fig. 8) discharged the concrete into a pressure tank, from which it was forced into the forms through 6-inch pipes under an air pressure of 100 pounds per square inch; 1,000 cubic feet of air per minute was consumed in the process. A ramp for supporting the discharge pipe and directing it to the top of the forms was built and mounted on a flat car, as shown in figure 9. As work progressed, a Rex Pumpcrete machine (fig. 10) replaced the pressure tank, giving more efficient pouring. A volume of 175 to 200 cubic yards of concrete was mixed and poured in a day, to make the average advance of 72 linear feet. The forms were removed 12 to 16 hours after pouring, unless they were found to be under pressure. The thickness of the concrete ranged from a minimum of 8 inches to a maximum of 30 inches, with all timber and steel supports covered by at least 5 inches. The following tabulation shows monthly concreting progress:

Date Commenced April 19, 1938.

	Linear feet	Batches	
April 1938	890	2,492	(2.8 cubic yards per foot; 568 pounds per cubic yard.)
May 1938	2,410	5,290	(2.2 cubic yards per foot.)
	76		Turnout (gunited).
June 1938	2,313	4,647	(2.0 cubic yards per foot.)
July 1938	1,300	2,737	(2.1 cubic yards per foot.)
Total	6,913	15,166	
Average per day	72	158	

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The side and flume invert were poured after concreting of the tunnel had been completed. Collapsible forms (fig. 11) were made in 10-foot sections to fit the finished tunnel. The reinforcing here consisted of a 1/2-inch round-steel rod in each corner of each pier with 3/8-inch round rods on 6-inch centers between piers. Sidewalk reinforcing consisted of 3/8-inch round steel rods placed horizontally on 12-inch centers. The concrete for this work was mixed in a 1/3-cubic-yard mixer and dumped into a hopper, from which it ran by gravity into the forms. An average of 0.3117 cubic yard of concrete was used in the flume per linear foot of tunnel; the excavation for the flume was 0.5494 cubic yard per foot of tunnel. The tabulation below shows the progress made in pouring the sidewalk and flume invert:

	Feet
June.....	2,754
July.....	2,943
August (17)...	1,378
	6,975

The following tabulation shows the quantity of concrete used per foot of tunnel in relation to the size and quantity of timber placed for support in driving the tunnel:

Size timber, inches	1/ F.b.m.t.	2/ F.b.m.l.	3/ C. y. e.	4/, 5/ C. y. c.
6 by 8	213.0	108.0	12.296	1.9567
8 by 8	285.4	109.1	12.634	2.2919
8 by 10	356.7	109.1	12.634	2.2919
10 by 10	448.0	110.2	12.976	2.6304
10 by 12	537.7	110.2	12.976	2.6304
12 by 12	648.4	111.3	13.322	2.9723
12 by 14	756.5	111.3	13.322	2.9723

1/ Feet board measure in posts and segments.
2/ Feet board measure in lagging per foot of tunnel.
3/ Cubic yards excavation per foot of tunnel (flume excluded).
4/ Cubic yards concrete per foot of tunnel (flume excluded).
5/ Includes 5 inches of concrete inside of timber.

ROADWAY

The roadway was surfaced with 1-1/2 inches of oil and gravel placed on 12 inches of cobble rock for drainage in wet sections and directly on the tunnel floor in dry sections. The surfacing was built up in three layers of oil and gravel; each lift was rolled by a 10-ton roller. The gravel used on the roadbed was screened to minus 1/2 inch and the oil was M. C. 4 heated to about 275°F.

SAFETY FEATURES

Operations were conducted in accordance with mine safety regulations of the State of Utah, and recommendations of the State mine inspector for the elimination of accident hazards were promptly followed.

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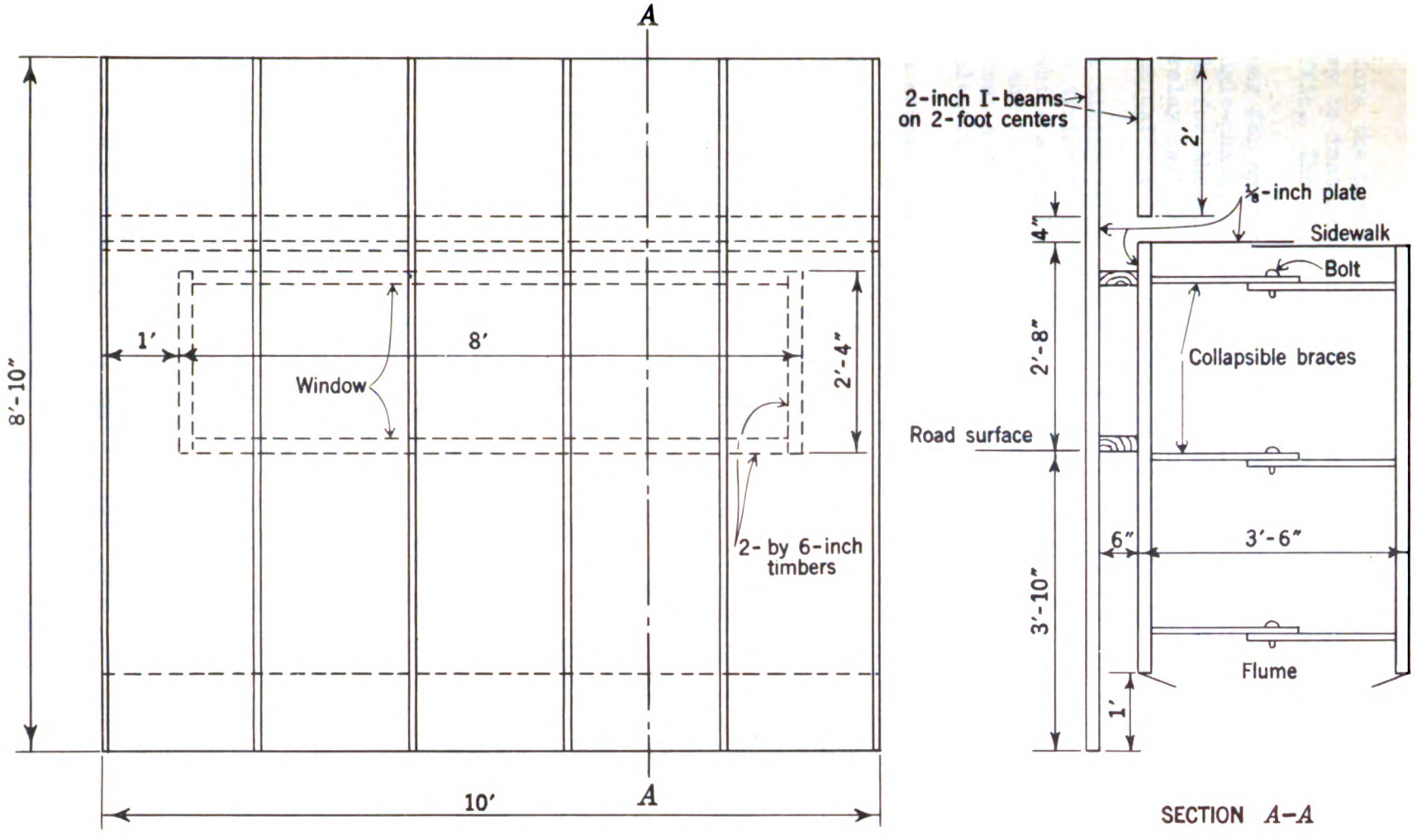

Figure 11.—Sidewalk and sewer forms.

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VEHICULAR-TRAFFIC CONTROL

Before the tunnel could be considered open for regular use, it was necessary to install an efficient traffic-control system to handle the one-way traffic. The control station is at the north portal.

Power for operating both the traffic and ventilation systems is supplied by a single-phase, 2,300-volt circuit. Transformers reduce this voltage to 115 volts for the lines leading to the traffic-control panel and motor-driven timing-relay switches. The alternating current is converted to direct current by copper oxide rectifiers before going to a photo-cell circuit used in the system.

All timing-relay circuits are interlocked between the two portals, so that when the timing relay at one end is energized a green light shows at that portal while a red light shows at the other. This light remains green for 2 minutes and 10 seconds, after which the relay at the other end is energized. This causes a red light to show at each portal and the controls are shifted to the electric counting equipment.

The counting units are the same at each portal. Each unit consists of two photoelectric cells connected through a system of selective switches. These electric-eye units are actuated by an object interrupting a beam of light, and the two cell units are necessary to prevent the counting of small objects. Cars with a space between the cab and body, such as dump trucks, would be counted as two cars if only one cell were used. The light beams of both cells must be broken simultaneously before the counting equipment will register. As traffic begins to flow in one direction, the electric eyes count out a preset number of vehicles; each interruption is registered through the selector switches. This causes a difference in potential to be built up, which is only equalized as the photoelectric cells at the opposite portal count out an equal number of vehicles. As the last car passes out of the tunnel the controls shift to the opposite portal, energizing that time-delay switch, the color of the traffic lights is reversed, and traffic proceeds in the opposite direction. The reset relays act each time the tunnel is clear of traffic by resetting the time delay. Contactors prevent the time delay from taking control until the tunnel has been cleared, and additional time-delay relays are provided to prevent the green light at each portal from being turned on until the red light has been on a definite length of time. When traffic in the tunnel becomes greater than is predetermined, the red lights at both portals are turned on.

The current that passes through the selector switches also goes through the alarm relay circuits. These relays are set for 15 minutes, so that if the potential between the selector switches is not equalized in this time a bell is sounded in the traffic-control station. This indicates that one or more vehicles remain in the tunnel and must be cleared before traffic can proceed again.

As a safety measure for power interruptions, a 6-volt battery circuit connected to a 115-volt control circuit through no voltage contactors flashes a red stop light at each portal until power is restored.

- Control of the traffic lights may be changed from automatic to manual operation by means of a simple transfer switch.

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VENTILATION CONTROL

As the tunnel was constructed to accommodate both vehicular and pedestrian traffic, provision has been made to control accumulation of carbon monoxide gas emitted from automobile exhausts. Natural ventilation would not be effective, as atmospheric pressure varies at different seasons of the year and often is nearly equal at both portals. Only during the winter months would there be an air current of velocity adequate to clear the tunnel of fumes. Four control rooms are situated in recesses in the tunnel. The latter are 300 and 1,900 feet from each portal. Three kv.-a. transformers reduce the 2,300 voltage to 115 volts for the continuous recording and sampling equipment.

Air is constantly being pulled from the tunnel to each of the control rooms at the rate of 0.5 cubic foot a minute by a Leiman positive-pressure blower size 26. This blower is directly connected to a 1/4-horsepower, 115-volt motor.

The air is cleaned in passing through a charcoal canister, dehydrated through a calcium chloride tower, and delivered to a Hopcalite cell. This cell is immersed in boiling water to maintain a constant sensitivity for recording purposes. The cell contains a thermocouple packed in dry Hopcalite. The Hopcalite is very sensitive to carbon monoxide and heats at the rate of 0.6° centigrade per one-hundredth part of carbon monoxide per one-ten-thousandth part of air. This temperature rise, acting on the thermocouple, sets up a minute electric circuit, which is transmitted to a recording potentiometer. The potentiometer gives a continuous record of the concentration of carbon monoxide per 10,000 parts of air. A break contact in the recorder is set to start the exhaust equipment when the carbon monoxide concentration reaches 3.5 parts to 10,000. This break contact deenergizes the traffic-control coils at the two portals, allowing them to close by gravity. The closed circuit at the lower portal sets the traffic light to red while the closed circuit at the upper portal starts a 440-volt fan motor and closes a Kinnear steel roller door installed to prevent a short circuit of air. The door closes 1 minute after the fan is started. The exhaust fan is operated at 600 revolutions per minute and has a capacity of 150,000 cubic feet a minute until the carbon monoxide concentration is reduced to 2.5 parts in 10,000. At this point the potentiometer break circuit reverses the above proceding and traffic returns to normal.

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